

material may be formed from one or more metallic materials, including but not limited to Group VI metals such as tungsten, and Group II metals such as barium. In one form, the layer of electron emissive material may be formed from materials including, but not limited to, aluminum tungstate and scandium tungstate. The thermionic cathode 122 may also be an oxide coated cathode, where a coating of the mixed oxides of barium and strontium, by way of example, may be applied to a metallic base, such as nickel or a nickel alloy. The metallic base may be made of other materials, including Group VI metals such as tungsten.

Getters 155 may be positioned within the housing 130. The getters 155 aid in creating and maintaining a vacuum condition of high quality. The getter has an activation temperature, after which it will react with stray gas molecules in the vacuum. It is desirable that the getter used have an activation temperature that is not so high that the x-ray device will be damaged when heated to the activation temperature.

The fiber optic cable 113 is adapted to transmit laser radiation, generated by the laser source 104 (shown in FIG. 3) and incident on the proximal end 113A of the fiber optic cable 113, to the distal end 113B of the fiber optic cable 113. The fiber optic cable 113 is also adapted to deliver a beam of the transmitted laser radiation to impinge upon the electron-emissive surface of the thermionic cathode 122. The beam of laser radiation must have a power level sufficient to heat at least a portion of the electron-emissive surface to an electron emitting temperature so as to cause thermionic emission of electrons from the surface.

In operation, the laser beam shining down the fiber optic cable 113 impinges upon the surface of the thermionic cathode 122, and rapidly heats the surface to an electron emitting temperature, below the melting point of the metallic cathode 122. Upon reaching of the surface of a electron emitting temperature, electrons are thermionically emitted from the surface. The high voltage field between the cathode 122 and the target element 128 (shown in FIGS. 3 and 4) accelerates these electrons, thereby forcing them to strike the surface of the target element 128 and produce x-rays. In one embodiment of the invention, a Nd:YAG laser was coupled into a SiO₂ optical fiber having a diameter of 400 microns. A 20 kV power supply was used, and a thermionic cathode made of tungsten was used. Only a few watts of power was needed to generate over 100 μ A of electron current. In another example, an infrared diode laser was used to achieve about 100 μ A of electron current with only 180 mW of power.

Another way to increase the efficiency of the laser heated thermionic cathode, besides using laser energy to drive the thermionic cathode, is to minimize heat loss due to incident laser radiation that remains unabsorbed by the thermionic cathode. FIG. 6 illustrates one embodiment of an electron source embodying the present invention, in which reflector elements 160 are included which reflect back to the thermionic cathode 122 incident laser radiation that was unabsorbed by the thermionic cathode 122. FIG. 6 shows an illustrative incident ray 152 of laser radiation which is unabsorbed and scattered by the thermionic cathode 122. The scattered ray 153 of laser radiation impinges upon the inner surface of the capsule 130 enclosing the radiation generator assembly 101. By placing reflector elements 160 at predetermined locations along the inner surface of the capsule 130, incident laser radiation that remained unabsorbed by the electron emissive surface of the thermionic cathode 122 is reflected back by the reflector elements 160 to the thermionic cathode 122, so that an optical cavity is

effectively created within the capsule. The coupling efficiency of the incident laser radiation to the thermionic cathode 122 is thereby significantly increased.

While the invention has been particularly shown and described with reference to specific preferred embodiments, it should be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. A therapeutic radiation source, comprising:

A. a probe assembly including an optical delivery structure having a proximal end and a distal end, said optical delivery structure being adapted for transmitting optical radiation incident on said proximal end to said distal end;

B. an optical source, including means for generating a beam of optical radiation directed to said proximal end of said optical delivery structure;

C. a radiation generator assembly coupled to said probe assembly, including:

a. an electron source, responsive to optical radiation transmitted to said distal end of said optical delivery structure, for emitting electrons, the electron source including a thermionic cathode having an electron emissive surface; and

b. a target element including at least one radiation emissive material adapted to emit therapeutic radiation in response to incident accelerated electrons from said electron source; and

D. means for providing an accelerating voltage between said electron source and said target element so as to establish an accelerating electric field which acts to accelerate electrons emitted from said electron source toward said target element;

wherein said optical delivery structure is adapted for directing a beam of optical radiation transmitted there-through to impinge upon a surface of said thermionic cathode, and wherein said beam of transmitted optical radiation has a power level sufficient to heat at least a portion of said surface to an electron emitting temperature so as to cause thermionic emission of electrons from said surface.

2. A therapeutic radiation source according to claim 1, wherein said optical source is a laser, and wherein said beam of optical radiation is substantially monochromatic and coherent.

3. A therapeutic radiation source according to claim 1, wherein said electron emissive surface of said thermionic cathode is formed of a metallic material.

4. A therapeutic radiation source according to claim 3, wherein said metallic material includes tungsten, thoriated tungsten, tungsten alloys, thoriated rhenium, and tantalum.

5. A therapeutic radiation source according to claim 1, wherein the emitted electrons form an electron beam along a beam path, and wherein said target assembly is positioned in said beam path.

6. A therapeutic radiation source according to claim 1, wherein said electron beam is characterized by a current in the approximate range of about 1 nA to about 1 mA.

7. A therapeutic radiation source according to claim 6, further including selectively operable control means for selectively controlling the amplitude of said beam current.

8. A therapeutic radiation source according to claim 1, wherein said electrons incident on said target element from said electron emissive surface are accelerated by said accel-

erating electric field to energies in the approximate range of 10 keV to 90 keV.

9. A therapeutic radiation source according to claim 1; wherein the means for providing an accelerating voltage includes:

a power supply, having a first terminal and a second terminal, and a drive means for establishing an output voltage between said first terminal and said second terminal, said power supply being electrically coupled to said radiation generator assembly by way of said first terminal and said second terminal.

10. A therapeutic radiation source according to claim 9, wherein said first terminal of said power supply is electrically coupled to said electron emissive surface of said thermionic cathode and said second terminal of said power supply is electrically coupled to said target element, thereby establishing an electric field which acts to accelerate electrons emitted from said electron emissive surface of said thermionic cathode toward said target element.

11. A therapeutic radiation source according to claim 9, wherein said second terminal is at ground potential.

12. A therapeutic radiation source according to claim 9, wherein said power supply further includes selectively operable control means for selectively controlling the amplitude of said output voltage.

13. A therapeutic radiation source according to claim 1, wherein said thermionic cathode includes a metallic base coated with an oxide.

14. A therapeutic radiation source according to claim 13, wherein said oxide includes barium oxide, strontium oxide, and calcium oxide, and said metallic base includes nickel.

15. A therapeutic radiation source according to claim 1, wherein said optical delivery structure includes a fiber optic cable.

16. A therapeutic radiation source according to claim 15, wherein said probe assembly includes a flexible, electrically conductive catheter enclosing said fiber optic cable.

17. A therapeutic radiation source according to claim 16, wherein said electrically conductive catheter is adapted for coupling said second terminal of said power supply to said radiation generator assembly.

18. A therapeutic radiation source according to claim 16, wherein the means for establishing an accelerating voltage includes a power supply, said power supply having a first terminal and a second terminal, said power supply being electrically coupled to said radiation generator assembly by way of said first terminal and said second terminal.

19. A therapeutic radiation source according to claim 18, wherein said fiber optic cable includes an electrically conductive outer surface, said electrically conductive outer surface being adapted for electrically coupling said first terminal of said power supply to said thermionic cathode.

20. A therapeutic radiation source according to claim 19, further comprising a layer of dielectric material between said electrically conductive outer surface of said fiber optical cable and an inner surface of said flexible catheter.

21. A therapeutic radiation source according to claim 1, further including:

a substantially rigid capsule, wherein said electron source and said target element are disposed within said

capsule, and further wherein said capsule defines a substantially evacuated interior region extending along a beam axis between said thermionic cathode at a proximal end of said capsule and said target element at a distal end of said capsule.

22. A therapeutic radiation source according to claim 1 wherein said therapeutic radiation includes x-rays.

23. A therapeutic radiation source according to claim 1, wherein power required to heat said electron emissive surface of said cathode so as to generate an electron beam forming a current of about 100 micro amps is between about 0.1 Watts to about 3.0 Watts.

24. A therapeutic radiation source according to claim 1, wherein said target element is spaced apart and opposite said electron emissive surface of said thermionic cathode.

25. A source of therapeutic radiation, comprising:

A. a radiation generator assembly, including:

a. an electron source for emitting electrons to generate an electron beam along a beam path, wherein said electron source includes a thermionic cathode having an electron emissive surface; and

b. a target element positioned in said beam path, said target element being spaced apart from and opposite said electron emissive surface, said target element comprising at least one radiation emissive element adapted to emit therapeutic radiation in response to incident accelerated electrons from said electron beam; and

c. a substantially rigid capsule, wherein said electron source and said target element are disposed within said capsule, and further wherein said capsule defines a substantially evacuated interior region extending along a beam axis between said thermionic cathode at a proximal end of said housing and a radiation transmissive window at a distal end of said housing;

B. a source of laser radiation;

C. a probe assembly coupled to said radiation generator assembly and including an optical delivery structure, said optical delivery structure having a proximal end and a distal end;

wherein said optical delivery structure is adapted for transmitting laser radiation, generated by said source and incident on said proximal end, to said distal end, and for directing a beam of said transmitted laser radiation to impinge upon said electron emissive surface of said thermionic cathode, and wherein said beam of laser radiation has a power level sufficient to heat at least a portion of said surface to an electron emitting temperature so as to cause thermionic emission of electrons from said surface;

D. one or more reflector elements disposed at predetermined locations along an inner surface of said capsule, said one or more reflector elements being operative to reflect incident laser radiation unabsorbed by said thermionic cathode back to said thermionic cathode.